ON THE APPLICABILITY OF AN ADVANCED DINSAR TECHNIQUE
NEAR ITOIZ AND YESA RESERVOIRS, NAVARRA, SPAIN.

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ABSTRACT

In this paper we show the applicability of orbital Synthetic Aperture Radar (SAR) Differential Interferometry (DInSAR) with multiple images for terrain deformation episodes monitoring. This paper is focused on the Coherent Pixels Technique (CPT). This technique has been tested with ERS SAR and ENVISAT ASAR data for the period 1992-2008 from The Itoiz and Yesa reservoirs. These ones, located in Navarra, northern Spain, are constructed gravity dams that stores the water from the Irati and the Urrobi rivers, and the Aragón river respectively. The results has been compared with theoretical results obtained using an analytical model.

1. INTRODUCTION

The Itoiz reservoir, located in Navarra, northern Spain, is a newly constructed gravity dam that stores the water from the Irati and the Urrobi rivers. The dam has a total height of 121 m, a total length of 525 m and a maximum water storage volume of 410 hm^3. Moreover, as Yesa reservoir is included into the Itoiz's scene we have considered a good opportunity to study this region. The Yesa reservoir drains an area of 2.181 km^2 in the upper Aragón river closed to Itoiz reservoir. See [3], [7] and [8] for more details and Fig.1.

Satellite Radar Interferometry (InSAR) has been proven to be a useful and powerful tool in tectonic areas for surveying subtle surface deformations over several years related to geodynamic phenomena. An advanced DInSAR observation technique, called the Coherent Pixel Technique (CPT) [2, 4 ,6], is being applied to study the existence of deformation areas in order to obtain mean velocities and time series of deformation.

We have studied the applicability of this technique to study the surface displacement field during the impoundment of the Itoiz water reservoir, and possible displacements in the surrounding of Yesa's dam. Specifically, we focus on the analysis of the stability of the left slope of the Itoiz and Yesa water reservoirs. See [3] for more details.
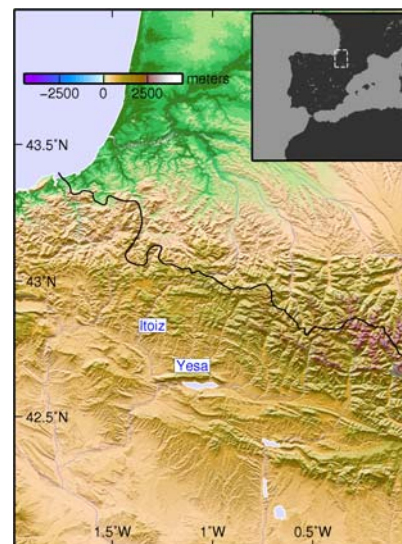

Figure 1. Situation of the Itoiz and Yesa water reservoirs.

In both of the studies the stacks used are composed by ENVISAT and ERS descending and ascending images concerning to the 2003-2008, and 1992-2008 periods respectively. We compare the observation results with an analytical model. Surface

water loads and the associated displacements are computed by means of the Boussinesq solution for a vertical pixel load on a homogeneous elastic half-space.

2. APPLIED METHODS

2.1 The Coherent Pixel Technique

We have applied an advanced DInSAR algorithm known as the Coherent Pixel Technique (see [2], [4] and [6]) in order to obtain deformation nearby Itoiz and Yesa water reservoir. To obtain DInSAR deformation maps, with both linear and non-linear terms of deformation, we have followed the procedure described in Fig. 2.
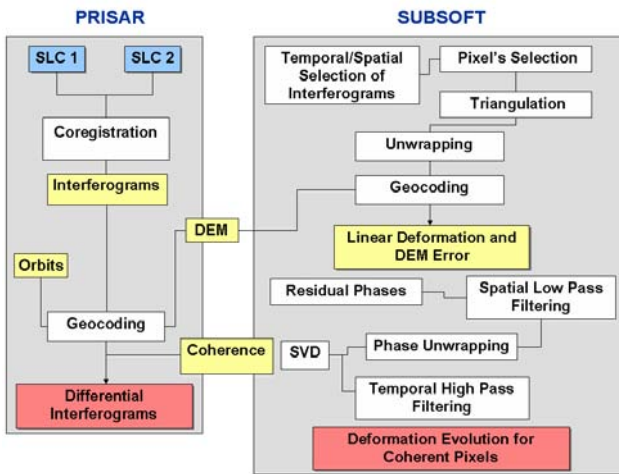

Figure 2. Block diagram for the linear (PRISAR) and non-linear (SUBSOFT) parts of CPT (see [2]).

We start with images focused from raw data. Using PRISAR software, we carry out the co-registration between each image to obtain interferometric phase. Both satellite orbits and Digital Elevation Model are used in order to generate differential interferograms. The result will be linear deformation maps from a set of low resolution interferograms (multi-looked) after estimating the DEM errors and the atmospheric artefacts.

With advanced DInSAR we will have more information from interferograms. For example by requesting a threshold so that the baseline from couple of images do not exceed a given value. This part of processing is carried out by SUBSOFT software. The selection criterion of the pixels to be processed is based on their coherence stability. This selection is related to a Delaunay triangulation. All this information is used to calculate the non-linear component of movement and the atmospheric artefacts by means of spatial low pass filtering and temporal high pass filtering. For this last step we apply the Single Value Decomposition (SVD) method for interferograms unwrapping.

2.2 Water load

On the other hand, surface water loads evolution is computed based on the Time Histories of the Lake Levels (THLL) and on the Digital Elevation Model (DEM) of the zone. THLL covers the period between 19/1/2004 to 10/5/2008 with a daily sampling rate. The combination of these two data sets gives us an opportunity to perform a highly accurate estimation of the evolution of the water loads and the space distribution in time, due to the relatively high spatial sampling rate of elevations in the DEM (25m x 25m). Surface deformations due to the evolution of water loads are computed for a homogeneous elastic halfspace. The surface vertical forces can be expressed by means of $F(x,y,t) = \rho gsh(x,y,t)$ where ρ is the water density, g is the gravity aceleration, s is the area of the spatial sampling rate from a digital elevation model of Itoiz area and $h(x,y,t)$ is the water column height that depends on the spatial location at surface (x,y) and the time t during the reservoir impoundment (see [1] and [9]). Given the deformation due to a surface pixel load, the total contribution of the entire lake water loads is computed by the sum of subsurface deformations due to the two dimensional array of forces of the lake. The time varying deformations due to the time varying reservoir loads, are then obtained by the computation of deformations due to the lake water level at a given time.

3. RESULTS

3.1 Itoiz results from ascending images

We do not have a good coherence (see Fig. 3) so the number of interferograms is less than the number of images. For this reason, the triangulation between pixels (see Fig. 3) do not allows us to obtain pixels on the right side of the dam. Pixels with a coherence greater than 0.25 in more than 45% of the interferograms are chosen. These are meshed using Delaunay triangulations, with arcs no longer than 2000 m. Close to the dam LOS displacements lower than ± 8 cm in 12 years are measured. (see Fig. 4 and 5)
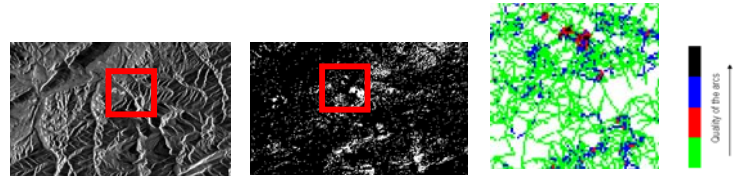

Figure 3. Amplitud image, selected pixels using the coherence criterion and Delaunay triangulations of study area (red square). Line colour indicates for the quality of the relationship between neighbouring pixels. Darker colour means higher quality.
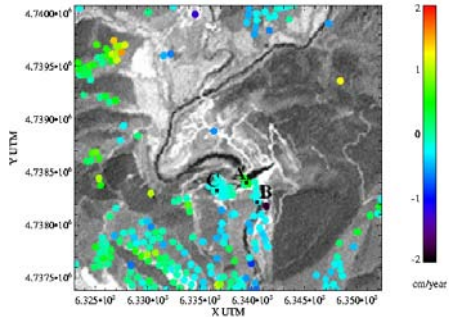
Figure 4. Deformation map. Darker colour means positive and softer colour means negative LOS velocity of displacements.
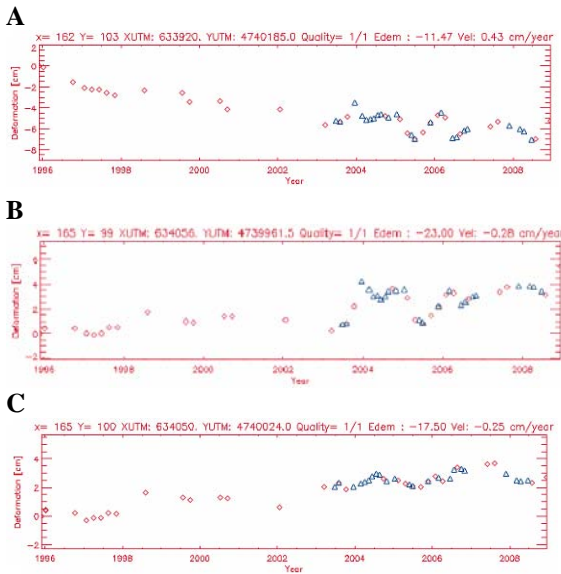

Figure 5. Time serie of A-C pixels. ERS data dates in red. ENVISAT data dates in blue.

3.2 Itoiz results from descending images

In this case we only have obtained good interferogram from ENVISAT images, with similar processing parameters of ascending processing. Five different pixels (A-E) have been selected in order to represent their temporal deformation series (see Fig. 7 and 8). We obtain better coherence so triangulation between pixels (see Fig. 6) allow us to obtain some pixels on the slope left of the dam. The pixels show a slight LOS displacement or stability.
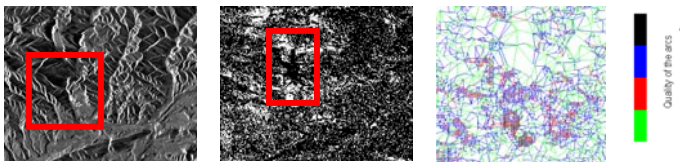

Figure 6. Amplitud image, selected pixels using the coherence criterion and Delaunay triangulations of study area (red square). Line colour indicates for the

quality of the relationship between neighbouring pixels. Darker colour means higher quality.
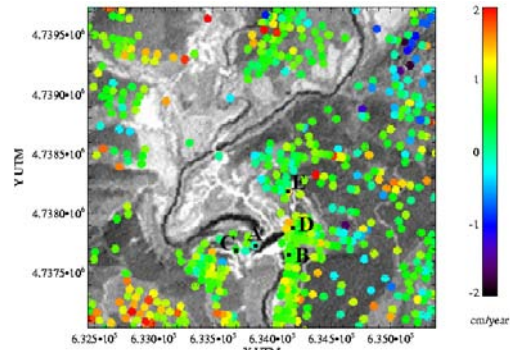

Figure 7. Deformation map. Darker colour means positive and softer colour means negative LOS velocity of displacements.
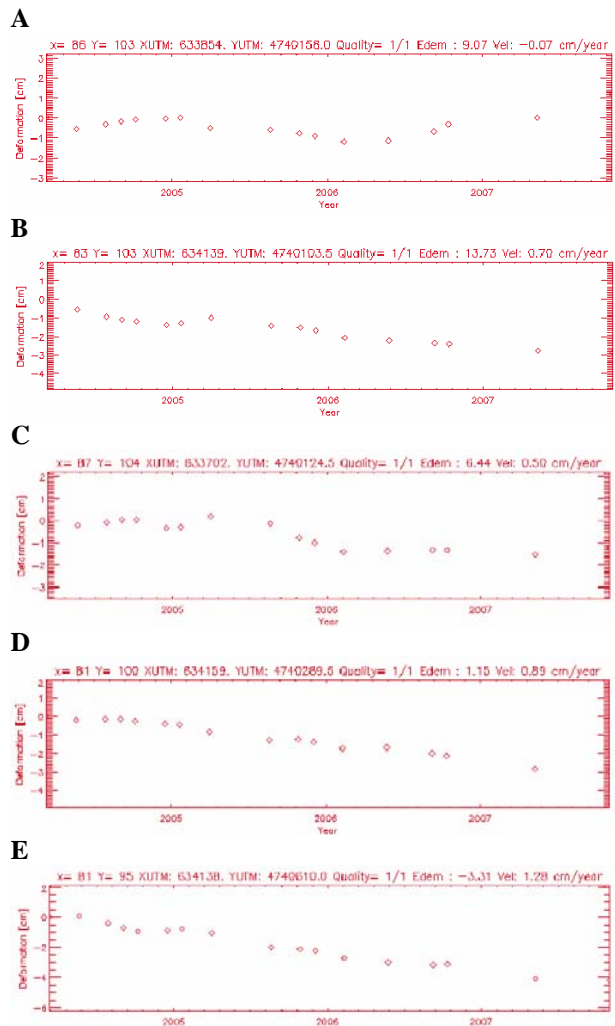

Figure 8. Time serie of A-E pixels. ENVISAT data dates.

3.3 Yesa results

For the two ascending processing of Yesa we do not have a good coherence so triangulation between pixels do not allows us to connect pixels. As in the Itoiz processing, we do not obtain more interferograms than images due to the low coherence in the area.

For descending processing coherence is better, and considering pixels with a coherence greater than 0.25, more than 45% of the interferograms are chosen. These are meshed using Delaunay triangulations, with arcs no longer than 2000 m.
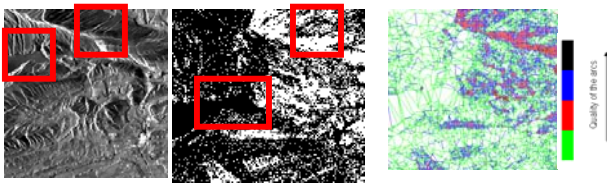

Figure 9. Amplitud image, selected pixels using the coherence criterion and Delaunay triangulations of study area (red squares). Line colour indicates for the quality of the relationship between neighbouring pixels. Darker colour means higher quality.

Eight different pixels (A-H) have been selected in order to represent their temporal deformation series (see Fig. 11). Some pixels show a maximum LOS displacement of around -12 cm in 15 years.
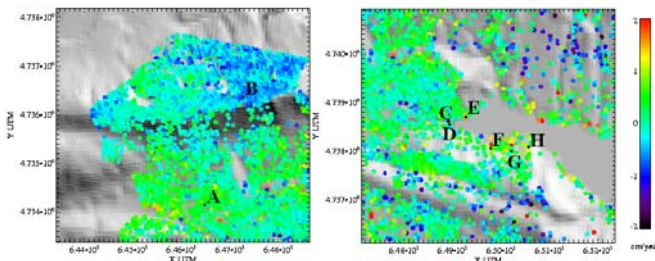

Figure 10. Deformation map of two interesting areas of Yesa. Darker colour means positive and softer colour means negative LOS velocity of displacements.

3.4 Water loads: Itoiz

For the computation of elastic displacement we assume a Poisson's ratio of $\upsilon=0.27$ and a Young Modulus of 0.90 Mbar. Fig. 12 shows vertical displacement (positive downward) at four different times.
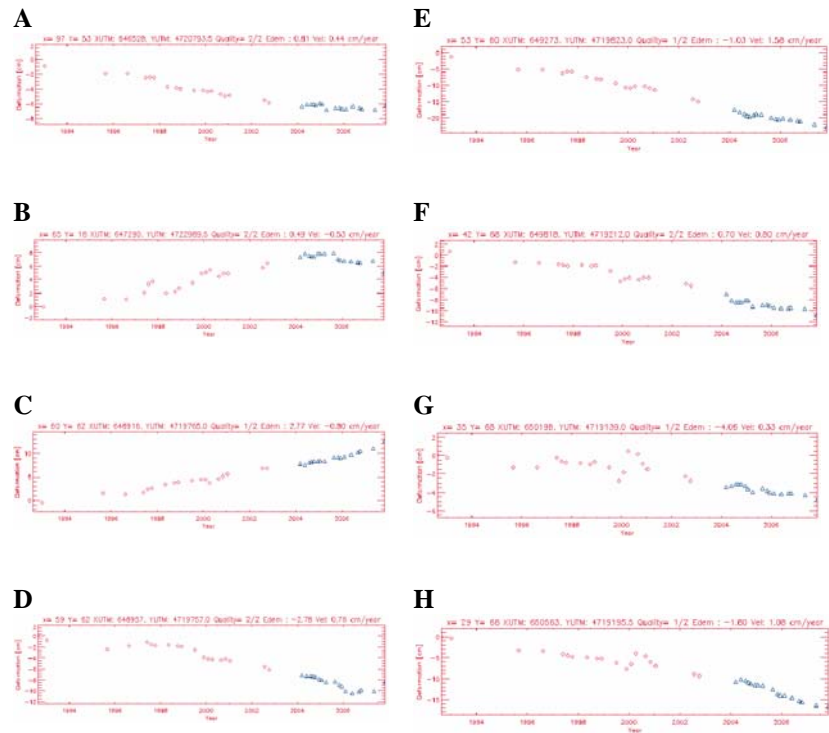

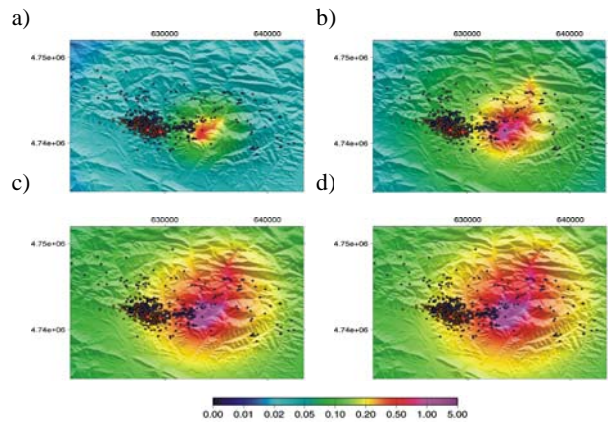*Figure 11. Time series of A-E pixels. ERS data dates in red. ENVISAT data dates in blue.*

Figure 12. Vertical surface elastic displacements due to water loads (cm). a) 18/09/2004 (earthquake mainshock, Mw=4.7); b) 01/06/2006, c) 01/07/2007, d) 18/04/2008 (maximum capacity), (see [1]).

4. CONCLUSIONS

We have obtained some results by means of the advanced radar interferometry Coherent Pixel Technique in order to study the possible deformations in Itoiz and Yesa water reservoir nearby. For this purpose,

we have used a set formed by ENVISAT and ERS ascending and descending images from 1992-2008 period. The DInSAR technique cannot estimate deformation in a complete way within the surrounding of Itoiz and Yesa dam due to existing vegetation, the low coherence found, layover, foreshortening and shadowing effects. But, despite those problems some interesting results have been obtained.

For ascending images from Itoiz, we have processed ENVISAT and ERS images from the 1996-2008 period. We get 56 interferograms from 54 images in order to obtain the deformation map. The results show slight deformation; a maximum deformation of 3 cm/year. The pixel closer to dam has a maximum subsidence of around 7 cm in 12 years. We cannot obtain coherence pixels on the slope left of the dam. Concerning descending images from Itoiz, we only have used ENVISAT images from 2004-2007 period due to the absence of good interferograms using whole stack of images. Measured displacements are located in the left slope of the Itoiz reservoir showing a maximun subsidence of about 4 cm in 3 years.

After processing ascending images from Yesa we show the impossibility to obtain good interferograms despite of the large number of images. Concerning to descending radar images processing from Yesa we obtain some results for the 1992-2009 period. Mainly subsidences with a maximum magnitude between 6 and 15 cm in the 15 years period studied.

On the other hand, theoretical vertical displacements in the vicinity of the Itoiz dam has maximum values of about 1.0 cm, occurring when the dam is at its maximum capacity and near and around the lake, as expected. The maximum value of deformations of the DInSAR results is about the same order of magnitude as the maximum displacements obtained by the theoretical elastic analysis.

Concluding, the results for Itoiz show a clear need of installing corner reflectors which will allow having control pixels in order to improve displacements detection capability. The installation of these corners have been done during August 2009. They are located in the surroundings of the Itoiz dam (see Fig. 13).

A complementary GPS observation network is going to be carried out around Itoiz dam area. GPS allows us to obtain 3D deformations continuous in time, but only with a few surface pixels, so both techniques could be combined in order to get better spatio-temporal resolution of the areas. More detailed CPT-DInSAR processing and combination of ascending and descending results and a more in depth comparison between observational and theoretical results will be done in the near future with the new necessary images.

Figure 13. Corner reflectors installed in Itoiz.

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